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Advanced Unmanned Search System (AUSS) Testbed

Search Demonstration Testing

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NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER RDT&E DIVISION
San Diego, California 92152-5000

J. D. FONTANA, CAPT, USN
Commanding Officer

R. T. SHEARER
Executive Director

ADMINISTRATIVE INFORMATION

The work was performed by members of the Ocean Engineering Division (Code 94), Naval Command, Control and Ocean Surveillance Center, RDT&E Division, San Diego, CA 92152-5000. The work was funded under program element 0603713N, project S0397.

Further information on AUSS is available in related reports that reprsent NRaD efforts through FY 92. The bibliography is found at the end of this report.

Released by
N. B. Estabrook, Head
Ocean Engineering Division

Under authority of
I. P. Lemaire, Head
Engineering and Computer Sciences Department

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SUMMARY

OBJECTIVE

Conduct an Advanced Unmanned Search System (AUSS) prototype search demonstration, operating the vehicle in a supervisory-controlled search mode and using immediate contact evaluation tactics. Evaluate vehicle performance and identify deficiencies.

RESULTS

The AUSS testbed was successfully deployed to perform supervisory-controlled search with an untethered vehicle.

Using improved sensors, more reliable equipment, and less conservative search tactics, search-area rates of 0.2 nmi^2/hr and better were obtained for a flat, featureless bottom with low false-target density. Immediate contact evaluation was used with impressive results.

CONCLUSIONS

Equipment failures and tactical errors made affected the results of the testing, but much was learned.

Based on the results of this demonstration, future contact evaluation times will be within 0.5 hour on a regular basis. This will be enhanced by the capability to vector to and hover over the target position during video and acoustic-tracking documentation.

Transmission of compressed and enhanced image information will decrease the burden on the acoustic link system, leading to higher area search rates than was demonstrated.

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INTRODUCTION

A search demonstration was conducted at the close of the Advanced Unmanned Search System (AUSS) FY 87 sea testing. The demonstration was performed late in the FY 87 effort to benefit from earlier system improvement and risk-reduction efforts.

SEARCH DEMONSTRATION

TERMINOLOGY

Several terms associated with AUSS search demonstration testing and used in this document are explained below:

Acoustic shadowing — a beam of an acoustic device is interrupted by a solid object.

Acoustic-tracking system — a system that uses underwater acoustics to determine the relative positions of equipment in the water. Distances are determined by the time taken for sound to travel from one position to another.

Acoustic transponder — a device that responds to sound, at one frequency, by transmitting at another frequency.

Bit-error rate — measure of accuracy in transmission of digital data, usually determined by the number of incorrect bits received divided by the total number of bits transmitted.

Broad-area search — rapid search of the ocean bottom using a low-resolution sensor. Classification (identification) of contacts perceived with broad-area-search sensors is not usually possible. A typical broad-area-search sensor is the SLS.

Contact — a search-sensor image perceived by the search system operator as an item of interest on the bottom of the ocean. Contacts may be real or "false" (i.e., not what is being sought).

Contact evaluation — close scrutiny of a contact to determine if it is a target of interest and, if it is, what are its characteristics. This normally involves the use of high-resolution sensors at close range to the contact.

Doppler sonar — an acoustic sensor used to determine the velocity and position of a vehicle with respect to the bottom of the ocean.

Fish-cycle acoustic tracking — a long baseline acoustic-tracking technique used to determine (fix) the position of a "fish" (i.e., the AUSS vehicle).

Forward-looking sonar (FLS) — an acoustic sensor used to scan the area forward of an underwater vehicle. For AUSS, the FLS has a mechanically scanned sonar

"head" that transmits and receives a beam very similar to the beam of the SLS. A sonagram is developed representing the area in front of the vehicle as the head is mechanically scanned back and forth across the bow.

Immediate contact evaluation — stopping during a broad-area search to perform a contact evaluation.

Long baseline acoustic tracking — a technique by which the position of equipment in the water is determined in three dimensions. This is done by determining the distance from the equipment to at least three bottom-moored transponders (a transponder net) whose positions are known.

Side-looking sonar (SLS) — an acoustic search sensor used for searching from an underwater vehicle advancing in a straight line at a constant velocity. Successive pings (perpendicular to the track of the vehicle) are sent out from the sonar that are narrow-beamed along the track of the vehicle, but are wide-beamed in the vertical. The times of return of these pings are used to determine the position on the bottom from which the sound was reflected.

Search-area rate — rate at which a search system is able to search the ocean bottom, usually expressed nmi^2/hr.

Sonagram — a visual representation of information collected by a sonar.

Supervisory control — control technique in which the human operator supervises the operation of a remote system. The operator communicates with the remote system infrequently. In between these communications, the remote system performs a series of preprogrammed functions selected by the operator. When finished with a series of preprogrammed functions, the vehicle awaits further instructions.

Target — a real contact.

OBJECTIVES

1. Conduct a representative search demonstration with the prototype AUSS.

2. Operate prototype AUSS as a supervisory-controlled search system.

3. Use AUSS immediate contact evaluation tactics.

4. Quantify AUSS prototype search demonstration using search times.

5. Evaluate AUSS prototype performance and define deficiencies.

TEST AREA

The FY 87 prototype search demonstration was conducted in the AUSS operations area (OPAREA) used for all previous AUSS dives. The area had a flat sandy silt bottom, and was near the center of OPAREA 37–03 shown in figure 1. The water was nominally 2,500-feet deep and this AUSS OPAREA was approximately one statute mile on a side. Slightly inside the four corners of this OPAREA were four long baseline system (LBS) acoustic-tracking transponders with floats suspending them approximately 100 feet above the sea floor. Six automobiles and three groups of three engine blocks were laid down on the ocean bottom, all of which were used as sonar and optical targets. The locations of the transponders, the automobiles, and engine blocks are pictorially shown in figure 2.

VEHICLE CONFIGURATION

The AUSS prototype testbed vehicle could not be optimized to simultaneously perform all the functions necessary in a search. Modifications to the "standard" AUSS testbed vehicle configuration to enhance the performance of subsystems was done at the expense of poor performance elsewhere. The AUSS testbed vehicle was configured for good performance of the acoustic link at 4800 bps, and for good performance of the fish-cycle tracking during the search demonstration.

The acoustic-link transducer and baffle were elevated above the body of the vehicle for good acoustic-link performance. The elevated transducer avoided acoustic shadowing previously experienced. A separate fish-cycle transducer was added to the tail end of the vehicle on its centerline and extended beyond the thrusters. The separate omnidirectional fish-cycle transducer communicated more reliably with the transponder net than when the fish-cycle function was performed by the acoustic-link hemispherical beam transducer. Vehicle hydrodynamics were compromised by the placement of these transducers.

The placement of the additional transducer on the tail end of the vehicle also presented a weight and balance problem. The moment and increased weight were compensated for by removing the still photograph camera from the vehicle and adding counterbalance weights in the appropriate locations. (The photographic capability of the vehicle was proven during previous dives).

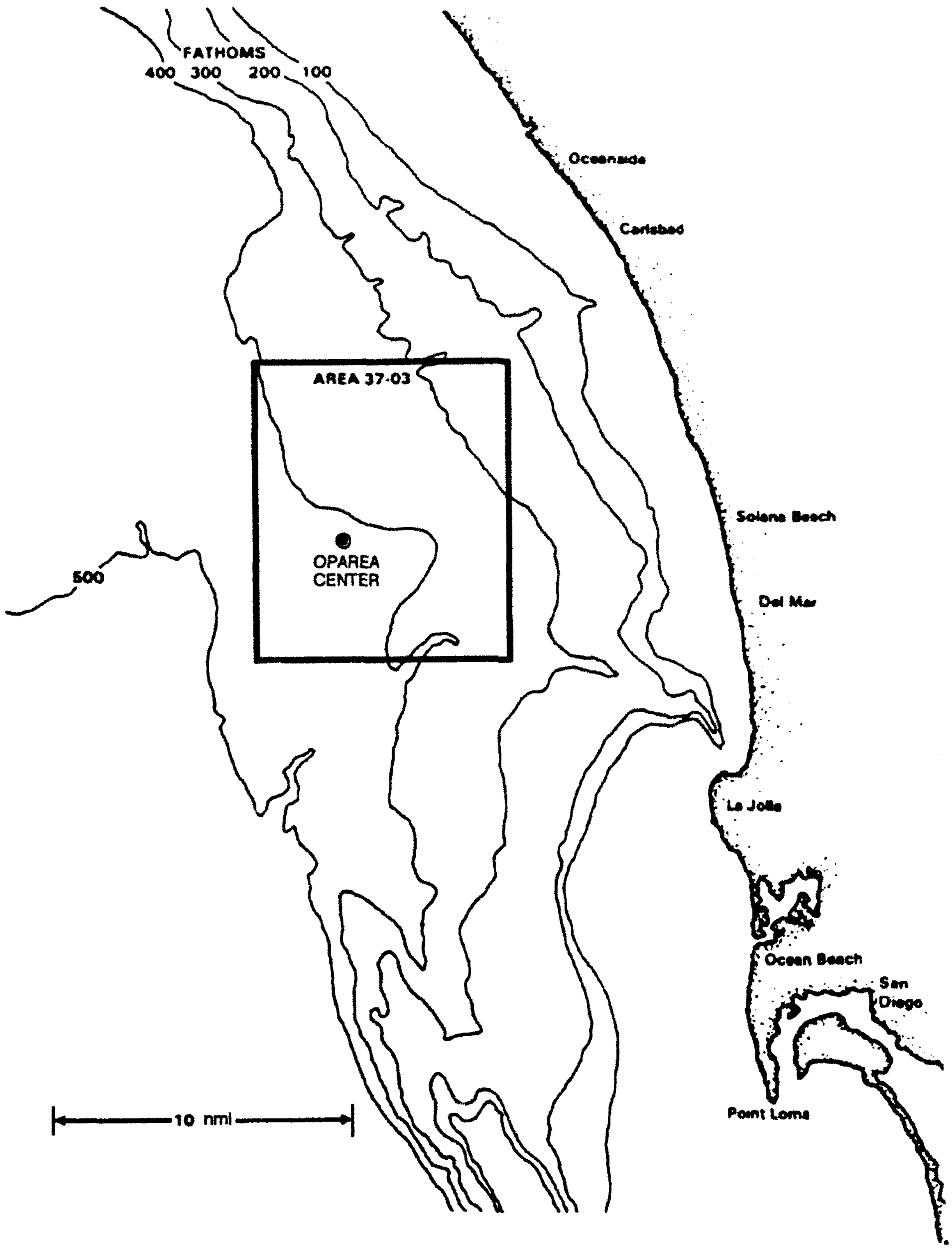

Figure 1. AUSS operations area.

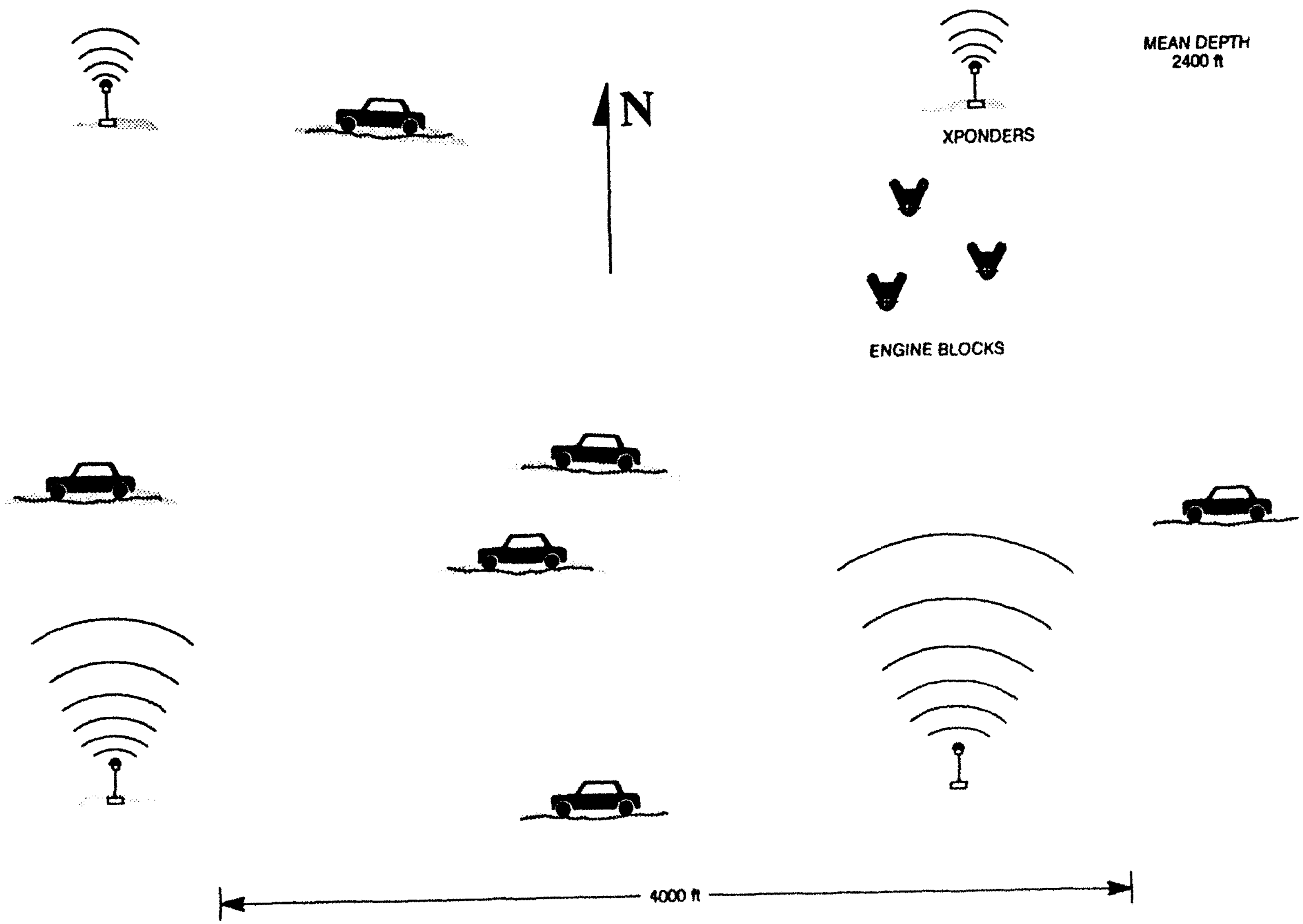

Figure 2. AUSS test site.

SETUP

After launch and descent, the AUSS vehicle was commanded to transit to a position in the northwest quadrant of the OPAREA. At this point, the vehicle was given commands via the acoustic link that set up an autonomous search pattern using Doppler sonar/compass navigation and SLS search. The search track was composed of three parallel legs: (1) the first leg from west to east for 3000 feet, an interleg turn; (2) a 3000-foot east-to-west search leg, an interleg turn; (3) and a final 3000-foot west-to-east search leg. The port and starboard SLS were set to scan on the 400-meter-range scale. The parallel legs were to be spaced such that there would be 150 percent coverage of the OPAREA (the 800-meter swath searched during the second parallel leg would overlay the first and third by 400-meters each, and would thus be covered twice).

Software to allow near-continuous transmission of the SLS data to the surface was not fully implemented for the demonstration. For this reason, the speed of the vehicle was limited to 1.6 knots to avoid along-track holidays (gaps) in the SLS data transmitted to the surface. The vehicle altitude was limited to 80 feet to assure continued performance of the Doppler sonar. Turns were run at speeds above 0.75 knot and no navigation stops were planned to avoid drop-out in the Doppler sonar navigation (a phenomenon that occurs at low speeds). Acoustic navigation fixes were to be made during the turns, when the SLS was not transmitting.

Transmission of all vehicle data to the surface was at 4800 bps, and all commands were sent to the vehicle at 1200 bps.

GENERAL APPROACH

A general approach is given here to the conduct of the demonstration including running search legs and performing contact evaluations.

The broad area search was conducted with the SLS on west-to-east or east-to-west search legs. All SLS contacts were immediately evaluated. When an SLS contact was made, the vehicle was immediately commanded to stop and an acoustic navigation fix was taken. The vehicle was next commanded to turn and scan perpendicular to the SLS track with its FLS. When necessary, the contact was closed in further and another FLS scan taken. Once a target was detected with the FLS, the vehicle was allowed to drift, but holding the same heading. After a few minutes of drifting, a second scan was made. The water current vector was determined by using range and bearing information from the two FLS scans.

The AUSS vehicle was next commanded to transit to a point down-current from the target position and turn into the current. The vehicle was then commanded to slowly "close in" on the target (transmitting sequential FLS sonagrams to the operator while

slowly thrusting forward) until the target was in view of the video camera. After assuring video documentation, acoustic navigation fixes were taken of the vehicle to pinpoint the target location.

A computer program called "X1Y1X2Y2" was used to compute a vector from the target position to the position at which the vehicle departed from its search track. The AUSS vehicle was commanded to transit back to the search track along the computed vector.

THE SEARCH

A representation of the actual track run by the AUSS vehicle during the demonstration is shown in figure 3. Points tagged by capital letters are positioned on the plot using acoustic navigation fixes of AUSS obtained with AUSS LBS fish-cycle tracking. Tracks run between the lettered points were plotted based upon AUSS Doppler sonar navigation data. The Doppler sonar navigation data were stored in the AUSS vehicle on-board flight recorder, and retrieved through the acoustic link after the demonstration was completed. The retrieved Doppler sonar data were stored on a disk in the AUSS Compaq computer. Figure 4 is a plot of the coordinates generated by the Doppler sonar and stored in the flight recorder. Differences between figures 3 and 4 will be discussed later in this report.

The search started at point A of figure 3. During the first leg, a target was detected on the port SLS. The contact evaluation of target #1 went as described in the preceding section, General Approach, except that incorrect use of the freshly-written program "X1Y1X2Y2" led to a reverse course to point D instead of back to the search track. The procedure was corrected and the vehicle was returned to point E to continue on leg 1 of the search track. The vehicle did not autonomously continue on its search track at this point since the initial track had been interrupted. The track from E to F was a single-leg search track and the transit from F to G was a dead-reckoning track initiated by the vehicle operator through the acoustic link.

After a short dead-reckoning correction (needed due to Doppler sonar navigation error resulting in overshoot at point G) the vehicle ran autonomously down search leg 2 and turned to pass through point H. Point H was obtained from the fish-cycle acoustic tracking while AUSS was advancing through the water (on the fly). Fish-cycle fixes are not normally possible on the fly because of tracking system interference generated by propulsion and the SLS. No targets were detected during the east-to-west portion of this path, although there were definitely targets within SLS range. The subject of detection and nondetection of targets is addressed later in this report.

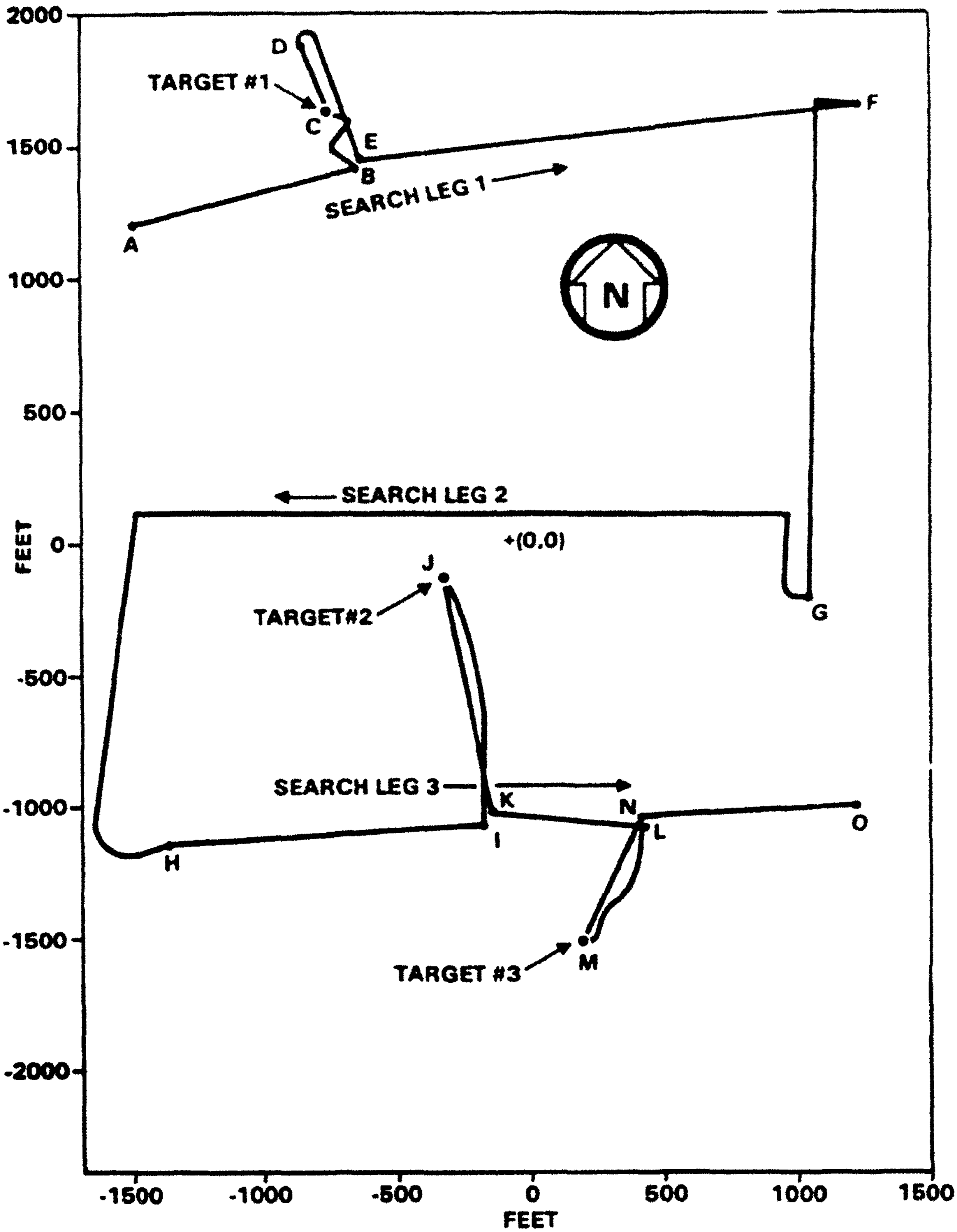

Figure 3. AUSS search demonstration vehicle track.

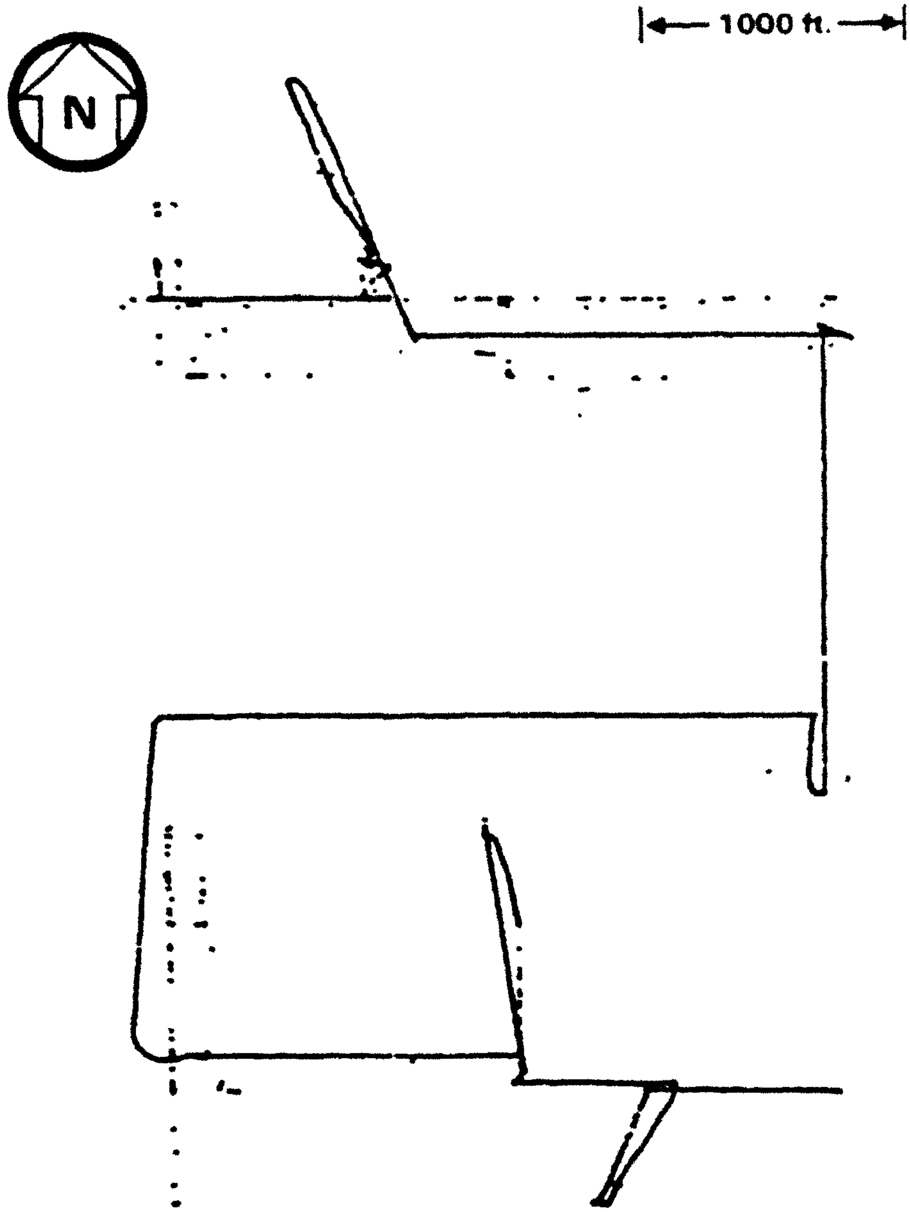

Figure 4. AUSS search demonstration plot of coordinates generated by a vehicle Doppler sonar.

The first part of leg 3 of the search path was a continuation of the path initiated near point G. Target #2 was detected on the port SLS. The target was out of the FLS range so it was closed using a "blind" dead reckon until it was within FLS range. Target #2 was closed to get video confirmation, and when the AUSS was returned to point K, another single-leg search was initiated.

Target #3 was detected on the starboard SLS. The initial transit from point N put the AUSS close to target #3 and the procedure to determine the current vector was not used. For final closing, the target was approached from an initial direction other than into the current which severely affected the amount of time it took to close it. In addition, target #3 was closed twice to get good video coverage. The times involved in accomplishing the various target contact evaluations are in the Search Statistics section of this report.

NAVIGATION PERFORMANCE

Acoustic fish-cycle tracking of the AUSS vehicle provided good navigation fixes, and is the basis of the track reconstruction in figure 3. Except for one case (see point H in figure 3) fish-cycle fixes were not obtained on the fly. Software changes had been implemented prior to the demonstration that should have allowed the SLS to cease operation during turns and possibly allow fixes on the fly, but a software "glitch" precluded this. To obtain reliable fish-cycle fixes, the vehicle was stopped, the period between acoustic-link-status transmission bursts was increased, and all search activity was ceased.

The Doppler navigation system on the testbed vehicle was inadequate for viable hovering and long-term search maneuvers. To accomplish this demonstration, several "tricks" were employed to produce a reasonable navigation result.

The Doppler sonar would "drop out" at velocities below 0.75 knot, so the search scenario was set up to keep the vehicle advancing at the highest speeds compatible with SLS and acoustic-link performance. Navigation stops within end of leg turns (which are planned as part of a normal AUSS search pattern) were eliminated by a software change to keep the vehicle moving around the turns. Any water current transverse to the track of the vehicle causes a translation normally at a rate less than 0.75 knot, which was therefore not detected by the Doppler navigation system. This effect was minimized by choosing east–west search legs roughly parallel to the current direction at the onset of the search demonstration.

Another error that was independent of the effects of dropout and water current was a drift error in the Doppler/compass navigation system. The absolute magnitude of the drift error increases as a function of time. This effect was minimized by running short search

legs, and taking absolute position fixes with the acoustic-tracking system whenever the vehicle was not advancing. Essentially, this demonstration was conducted using the Doppler/compass navigation system as a dead reckoner to navigate between points determined accurately using the acoustic-tracking system.

The ability to hover over a target during optical documentation is required for contact evaluation. The AUSS vehicle was not hovered during this demonstration, but was slowly driven over the target position while optical documentation was obtained on the fly. Acoustic-tracking-position fixes were obtained next, with the vehicle drifting "near" the target position. It was not possible to hover the AUSS testbed vehicle due to the 0.75-knot dropout in the Doppler sonar and general noise in its output.

Figure 3 is a representation of the actual track run by the AUSS vehicle as determined by the acoustic-tracking fixes. Figure 4 is a plot of the points stored in the vehicle flight recorder acquired from the Doppler navigation system. The successive points plotted in figure 4 are subject to accumulative errors due to system drift, and translations not measured by the Doppler due to water current and velocities below 0.75 knot. A comparison of figures 3 and 4 shows the effect of these cumulative errors. If the path AB is observed in figure 3 and compared to the same path in figure 4, it is seen that the Doppler system controlled the vehicle on what it sensed to be a good west to east course. In reality, between the fixes A and B, it is seen (from figure 3) that the vehicle traveled a significant distance to the north. Between the points B and E, the vehicle was operated at very slow speeds and was subjected to water current translations not measured by the Doppler system. The vehicle operator was able to fairly accurately navigate the vehicle with Doppler/compass dead reckoning from point D to point E near point B, but observation of figure 4 shows a large accumulated error in the Doppler position coordinates between where the vehicle left the search leg and returned to it. Further comparisons of figures 3 and 4 yield similar information on the inadequacy of the Doppler navigation system on the testbed vehicle.

SEARCH STATISTICS

A log was kept of the time each event in the demonstration occurred so that it is possible to determine the time required to perform the various search phases.

Table 1 is a summary of some search demonstration statistics. This search was conducted very conservatively in that 50 percent of the search area was covered twice. This conservatism was necessary because of uncertainty in the performance of the navigation system prior to the demonstration. About 31 percent of the demonstration time was lost due to failures and miscellany. This 31 percent loss would be reduced significantly with improved AUSS equipment and more time spent operating the AUSS in actual search scenarios. With no search path overlap and no failures and miscellany, the search-area rate in table 1 would be 0.19 nmi^2/hr.

Table 1. AUSS search demonstration results summary.

AREA COVERED =	0.33 nmi^2
TOTAL TIME =	3 hrs 45 min
TARGETS EVALUATED =	3
RAW AREA SEARCH RATE =	0.089 nmi^2 hr
RAW AVERAGE TIME PER CONTACT =	47 min
AREA COVERED TWICE =	50 %
BREAKDOWN:	
ON-TRACK SEARCH	53 min
CONNECTING TRACKS	21 min
ACTIVE CONTACT CLOSURE	70 min
RETURNS TO TRACK	11 min
FAILURES	33 min
MISC.	37 min
	3 hr 45 min

Table 2 focuses on target contact evaluation statistics. Targets were detected and closed on both sides of the search track at various distances. There was a significant amount of time lost due to equipment failures and tactical errors as seen in notes 2, 3, and 4. The corrected times (after eliminating failures and tactical errors) for overall

contact evaluation are 33, 35, and 29 minutes. The average corrected time for contact evaluation is 32 minutes.

TARGET DETECTIONS

All targets detected and evaluated during this demonstration were automobiles previously deployed. Operators of the AUSS vehicle ignored previous knowledge of the positions of targets in the OPAREA during the demonstration. Table 2 shows there were targets detected on both sides of the search path at three different ranges (75 meters, 300 meters, and 150 meters).

Using target #2 as an example, a representation of the series of images transmitted to the operator from the vehicle is shown in figures 5 through 8. During the SLS search, the vehicle advanced at a speed computed by the vehicle to avoid holidays in the along-track sonagram. Successive sonar scans to the port- and starboard-side of the vehicle were processed and transmitted to the surface via the acoustic link. Figure 5 is the sonagram presented to the operator for the port SLS in which target #2 was detected. Starting from the bottom of the screen, horizontal video scans originating from the far right of the screen were stacked upon previous scans as the vehicle advanced. The intensities of the pixels in this sonagram were related to the intensities of the sonar returns from ranges starting at 0 at the right of the screen to 400 meters at the left of the screen. The region of minimal return at the right of the screen represented the water column between the vehicle and the bottom directly below the vehicle. Target #2 was detected and identified on the sonagram by several high-intensity pixels in close proximity at a range of approximately 300 meters.

Table 2. AUSS search demonstration target contact evaluation statistics.

TARGET #	RANGE FROM SLS TRACK (meters)	CONTACT EVALUATION TIME (minutes) (note 1)
1	75 to port	62 (note 2)
2	300 to port	40 (note 3)
3	150 to stbd	40 (note 4)

Notes:

1. Included in contact evaluation are:

   a. Stop vehicle

   b. Fix vehicle position on SLS track with acoustic-tracking system

   c. Reacquire contact on forward-looking sonar (FLS)

   d. Determine current vector using FLS sonagrams of contact while vehicle drifts

   e. Calculate position down-current of contact from which to start final closing

   f. Close in on target and obtain video "snapshot" image

   g. Obtain acoustic-tracking fix of vehicle while over the contact (to mark the contact location).

   h. Calculate a vector for the vehicle to travel back to the position at which the SLS search track was broken

   i. Close back to search track

   j. Obtain navigation fix on vehicle to confirm it is back on the search track

   k. Reinitiate search on remainder of track

2. This time includes 29 minutes lost due to a computer malfunction and operator error. The corrected time would be 33 min.

3. Five minutes were lost reinitiating navigation transponders that had timed out (this reinitiation procedure is required every 5 hours during operations). The corrected time would be 35 min.

4. First video image of the contact was obtained 28 minutes after the SLS detected it. Of the contact evaluation total time, 11 minutes were expended reacquiring the contact for a better video image. Corrected time would be 29 min.

Figure 5. Sonagram for the port SLS in which target #2 was detected.

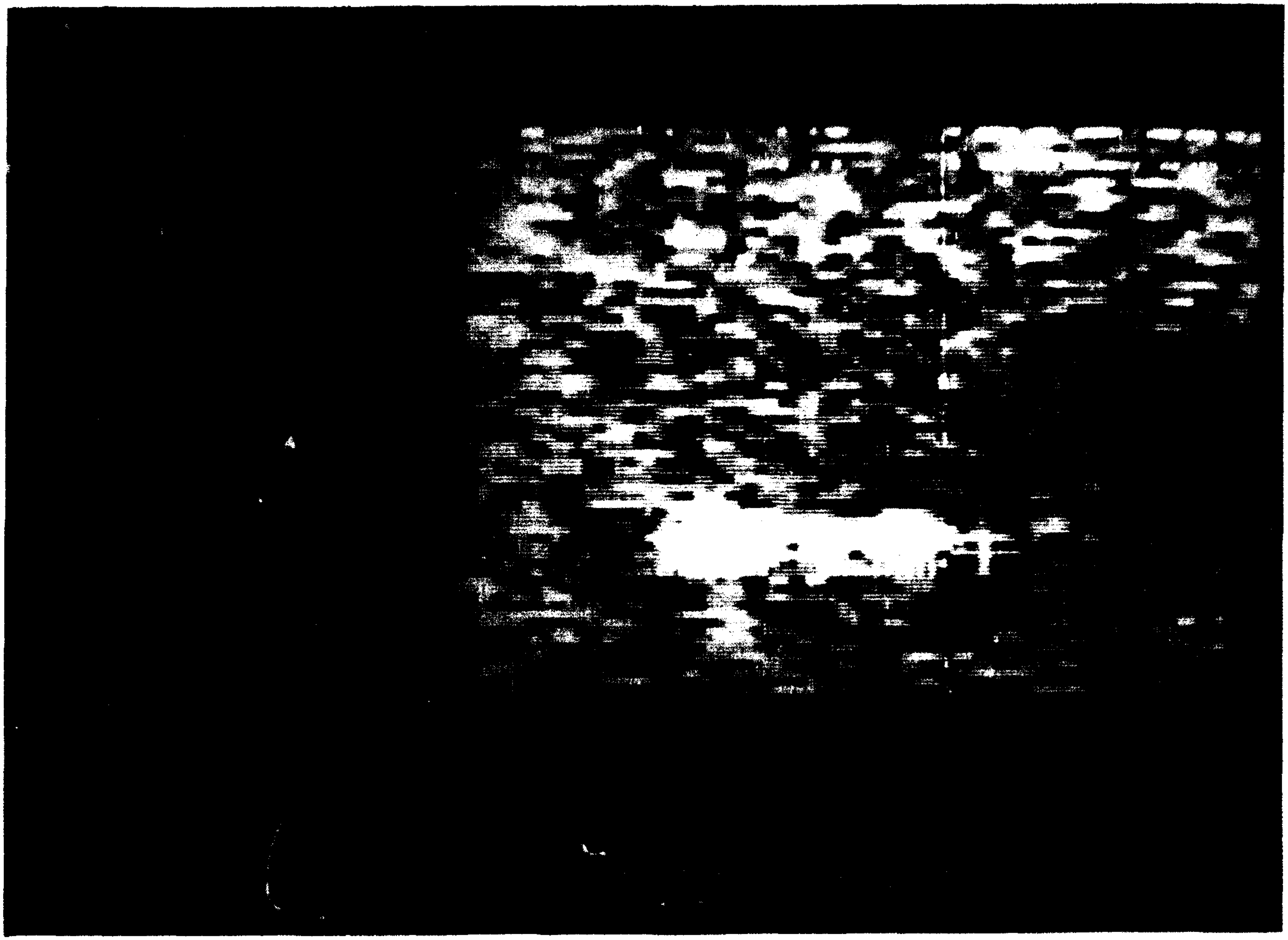

Figure 6. FLS sonagram of target #2, 25-meter-range scale.

Figure 7. Low-resolution, 4-bit video image of target #2.

Figure 8. High-resolution, 6-bit video image of target #2.

After maneuvering the vehicle into a position down-current from the target, the vehicle operator used the FLS to scan the target as the vehicle advanced toward it. Figure 6 is one of many FLS sonagrams obtained while closing in on target #2. The intensities of the pixels in this FLS sonagram were related to the intensity of the sonar returns from ranges starting at 0 on the left to 25 meters on the right-hand side of the screen. The vertical scale of the FLS sonagram was the sonar head angle with respect to the vehicle. The horizontal video scan at the vertical center of the screen represents the scan from directly ahead of the vehicle. Video lines above and below represent port- and starboard-side of the target respectively.

The operator commanded a picture to be taken when the vehicle was over the target. The command initiated a strobe that illuminates the bottom below the vehicle as a frame was "grabbed" from the video camera viewing the bottom. Figure 7 is the low-resolution, 4- bit video image of target #2 transmitted to the operator. After the operator was satisfied the low-resolution image represented a target of interest, he retransmitted the image with higher resolution (for a more detailed look) as was done for target #2 and shown in figure 8.

The video frame grabbed from the video camera could also be recorded on the vehicle on-board VCR as was done for target #2 and shown in figure 9. The image on the VCR was uncorrupted by the processing and transmission associated with the acoustic link, but was retrievable only after the dive is completed. Although the 35-mm camera was not installed during the demonstration dive, a still photo of target #2 obtained during a previous dive was included as figure 10 for comparison with the video images.

Evident from figures 2 and 3, targets were missed during leg 2 of the demonstration. Reconstruction of the search path and previous information on the location of these automobile targets indicated that they were missed at 40 meters to starboard and at 70 meters to port. These targets were missed due to sonagram display hardware failures and poor acoustic telemetry. A post-dive sonagram was extracted from the vehicle VCR audio track and is presented in figure 11. This sonagram shows that a return suggesting a target was processed by the port SLS system along leg 2 of the search. The target is displayed as a cluster of illuminated pixels near the sonagram upper right- hand corner. No starboard sonagram is available for leg 2 of the search since only one SLS output at a time could be recorded on the vehicle.

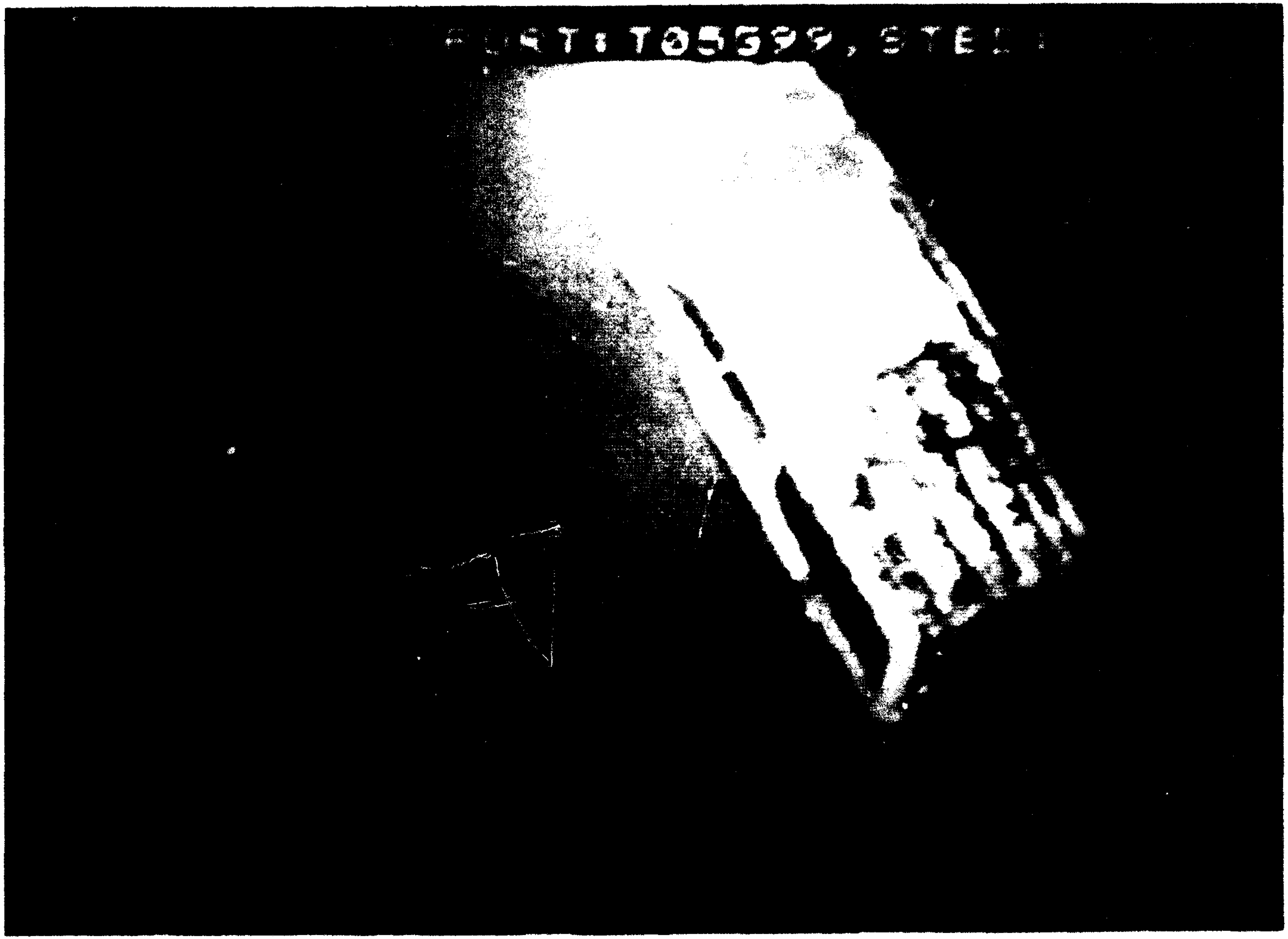

Figure 9. Video image of target #2, altitude 30 feet.

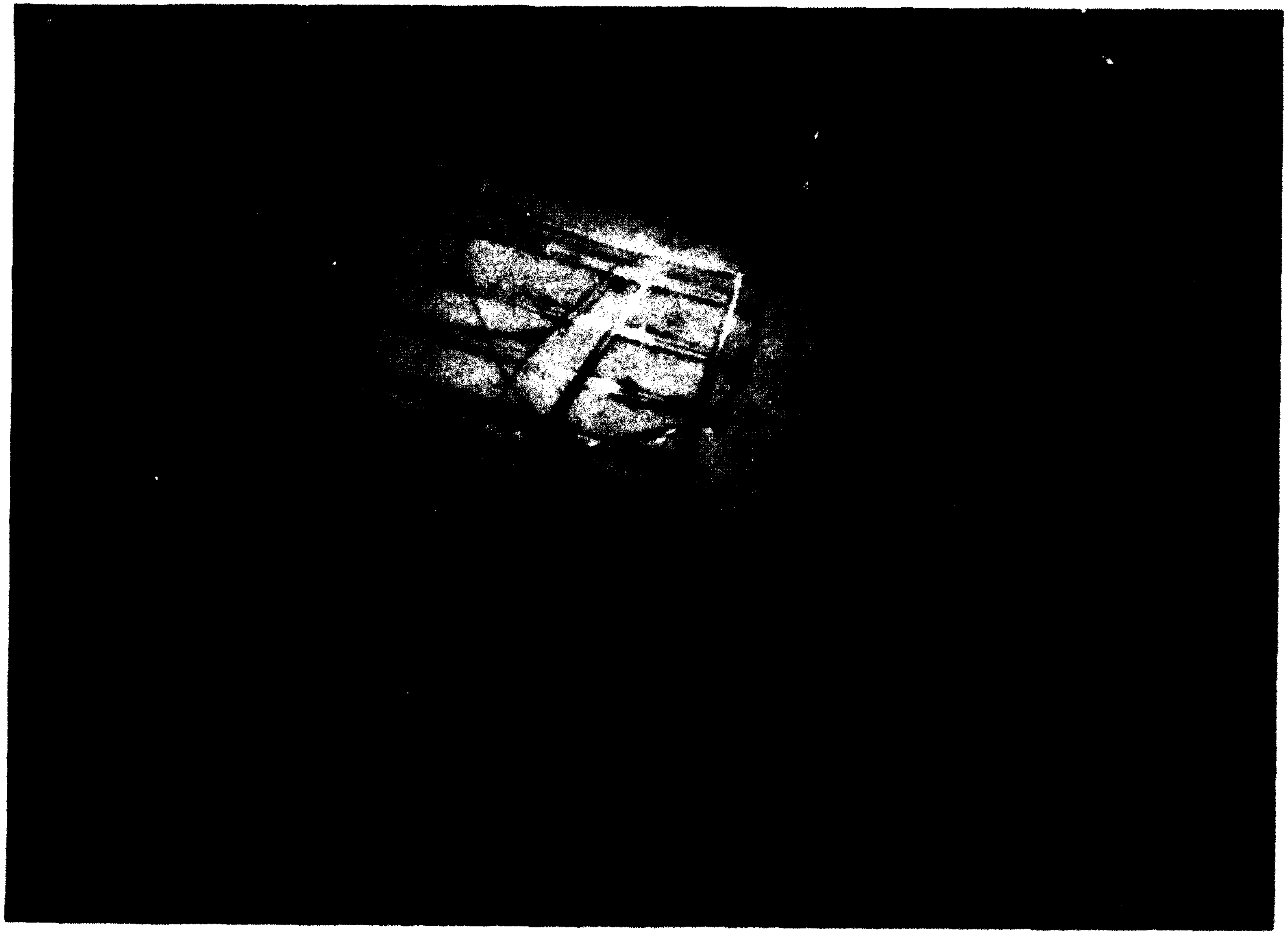

Figure 10. Still photograph of target #2.

Figure 11. Post-dive sonagram by the port SLS, leg 2.

CONCLUSIONS AND RECOMMENDATIONS

The testbed AUSS system was successfully used to perform supervisory controlled search with an untethered vehicle during this one-dive search demonstration. There were several tactical errors and failures of equipment that affected the results of the testing, but much was learned.

Using improved sensors, more reliable equipment, and less conservative search tactics, search area rates of 0.2 nmi^2/hr and better were obtained for a flat, featureless bottom with low false-target density.

Immediate contact evaluation was used with impressive results. Contact evaluation times (time between SLS detection of a contact and return to search track after evaluating the target) will be within 1/2 hour on a regular basis in the future, based on demonstration results. This will be enhanced by the capability to vector to and hover over the target position during video and acoustic-tracking documentation.

Target images were clearly presented to the operator as long as the system was operating properly. Data compression and image enhancement of sensor information sent to the operator is required. Transmission of compressed and enhanced image information will decrease the burden on the acoustic-link system, and improve the images presented to the operator. The overall result of these efforts will lead to higher area-search rates than was demonstrated.

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J. Walton

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The results of a search demonstration conducted at the close of the Advanced Unmanned Search System (AUSS) FY 87 sea testing are detailed in this report. Operating in a supervisory-controlled mode and using immediate contact evaluation tactics, the AUSS testbed was successfully deployed. Lessons learned will significantly improve future sea testing and the next-generation system design.

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Jim Walton	(619) 553-1879	Code 941